Xenon Recovery System for the PHENIX TRD

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Introduction

For the upgrade of the PHENIX Time-Expansion Chamber (TEC) to a Transition Radiation Detector (TRD) the operating gas has to be changed from the current 90%Ar + 10%CH_4 (P10) to a mixture that converts the created TR X-rays into electron clusters. Our choice is 45%He + 45%Xe + 10%CH_4.

The current system vents the gas after use, which would be too expensive with Xe, so from the beginning the TEC gas system was designed as a semi closed system.

Fig. 1 shows a schematic of the TEC/TRD gas system with the Xe recovery system placed on the current vent line (red box, upper right). The physical location of the recovery system is the PHENIX gas pad. All controls and alarm functions integrate into the existing TEC gas system.

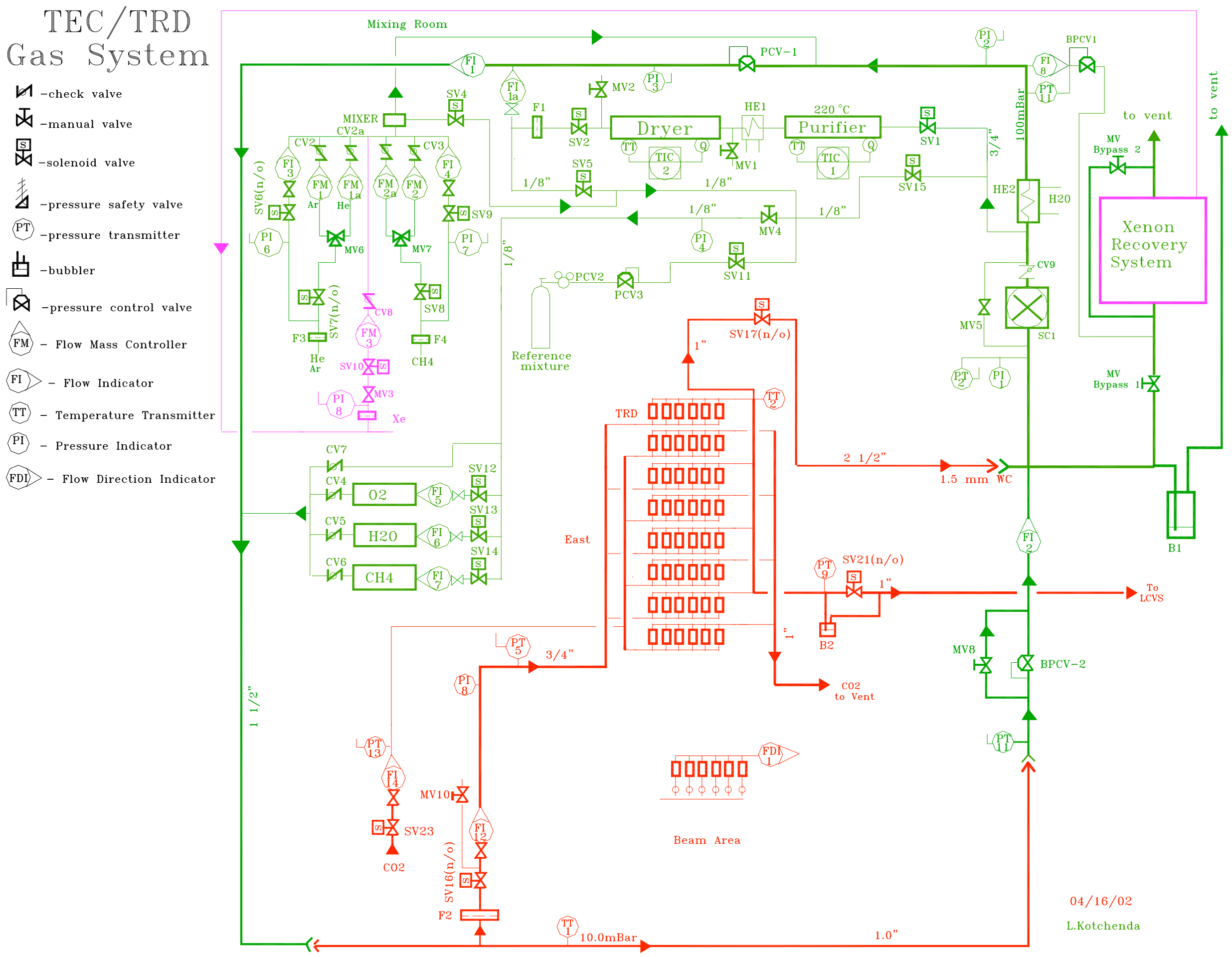

Fig. 1. PHENIX TEC/TRD Gas System

The recovery system extracts Xenon from the 45%He+45%Xe+10%CH_4 mixture venting from the chambers by use of a cold trap. The collected solid Xe is recovered, first to a transfer bottle in liquid form and then placed as a gas into commercial storage cylinders for re-introduction into the system.

<u>The Xenon Recovery System</u>

The Xenon recovery system itself is shown in Fig.2. It includes two low temperature cryostats, each capable of accumulating up to 6 liters of liquid Xenon. The cryostats have two stages of Xenon separation at different cryogenic temperatures, a first stage at 161K and a second stage at 110K where solid Xenon will be collected. For normal operation only one cryostat will be in the running mode, with the second one in standby. For TRD purging or power failures, both cryostats will be employed.

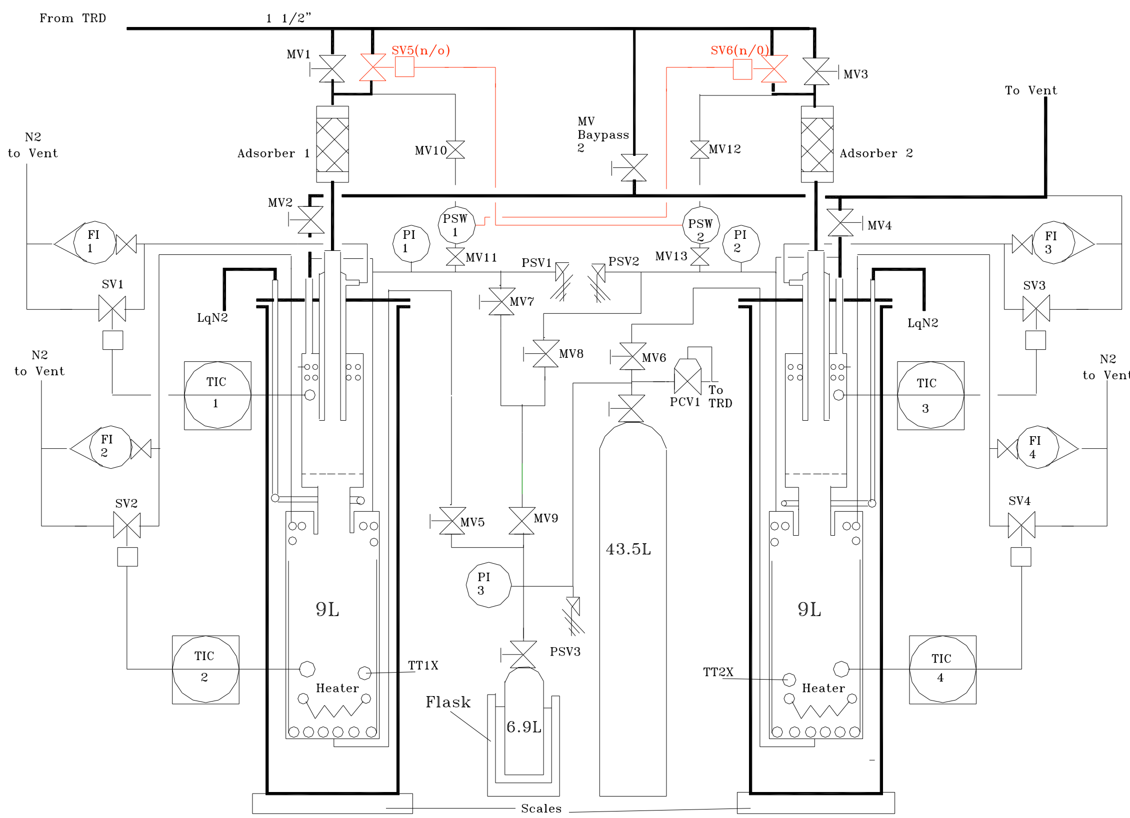

Fig.2. Xenon recovery system

The coolant, liquid Nitrogen (N_2), flows through each of the two stage heat exchangers, controlled by a temperature-indicating controller (TIC). Two commercial 200 liters Dewars (CRYOFAB CFN-200-SS) with a custom transfer-line (Fig.2c) will be used to supply the cryostats with liquid N_2, see Fig.2b.
Each cryostat has an absorber on the mixture input line to remove CO_2 and H_2O remains.

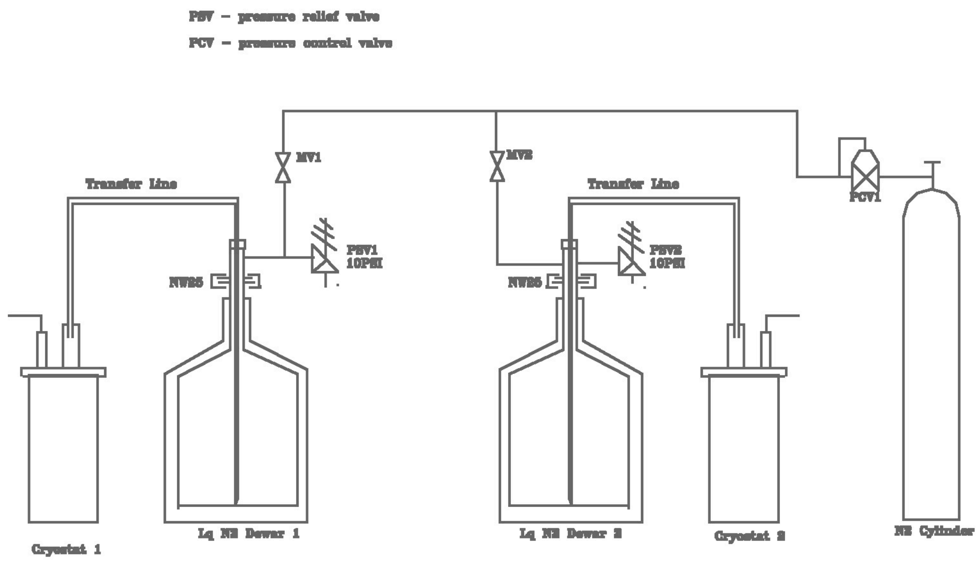

Fig.2b. Simplified view of the Nitrogen Supply flow on the Xenon recovery system

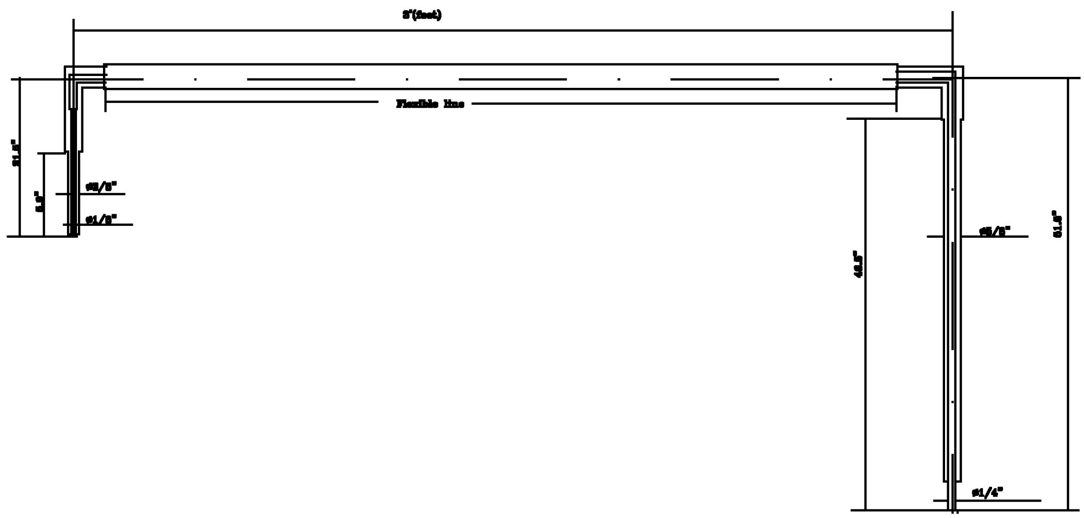

Fig.2c. Detail of the N_2 supply transferline

In case the input line of the operating cryostat is plugged up operation will be switched over to the second cryostat automatically by the pressure switch PSW1 or PSW2, set at 3mm WC.

A scale measures the amount of Xenon, recovered by the second cryostat stage.

1 PSI relief valves (PSV1, PSV2) on the second stage and the cryostats vent lines prevent accidental overpressure of the cryostats stages.

Each cryostats second stage has a RTD (100m) temperature transmitter (TT1X, TT2X) connected to the TEC/TRD gas system readout electronics to monitor the cryostats internal temperature and pressure. The shift crew will be informed by an audible and optical alarm in the case the temperature and/or pressure exceeds a predefined set point (130K/3mmWC).

Xenon Recovery Cryostat Design Details

The cryostat design is shown in Fig.3. Its demountable vacuum jacket allows access to the inside parts. The cylindrical part of vacuum jacket (1)[1] is made from 1.2mm thick stainless steel with a diameter of 200mm. The vacuum jacket bottom plate (2) is 2 mm thick.

The first cryostat stage (3) is connected to the vacuum jacket flange (4) by the input (5) and output (6) mixture pipes and thermometer pipe (7). The top part of first stage contains a heat exchanger (8) using for Xenon condensation.

A heat exchanger (9) on the mixture input pipe (5) cools the mixture before it enters the first stage. Outgoing Nitrogen gas from the heat exchanger (8) is used as the coolant. The inner diameters are 14.5mm for the mixture input pipe and 7.5mm for the output pipe (6).

The second cryostat stage is connected to the first one by a 52.6mm inner diameter pipe and to the flange (4) by several pipes (liquid Xenon Out, Xenon Gas/Heater Out, two thermometers pipes).

The second stage vessel is made from 1mm stainless steel.
Inside are:

- two heat exchangers (11 top and 12 bottom, connected in series),
- a heater (13),
- copper temperature equalizer (14),
- thermometers (TT1X or TT2X).

For thermal insulation the second stage is covered with many layers of vacuum insulation (15).

During construction the assembly was pressurized to an absolute pressure of 2 atm for the inner part, with 0 atm in the vacuum jacket and 1 atm pressure outside.

For the initial startup a pump will establish a sufficient vacuum in the jacket, after that all bolts from the top flange need to be removed so that the top flange can act as a relieve valve is case of overpressure in the jacket.

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[1] Numbers in brackets refer to the drawing in Figure 3.

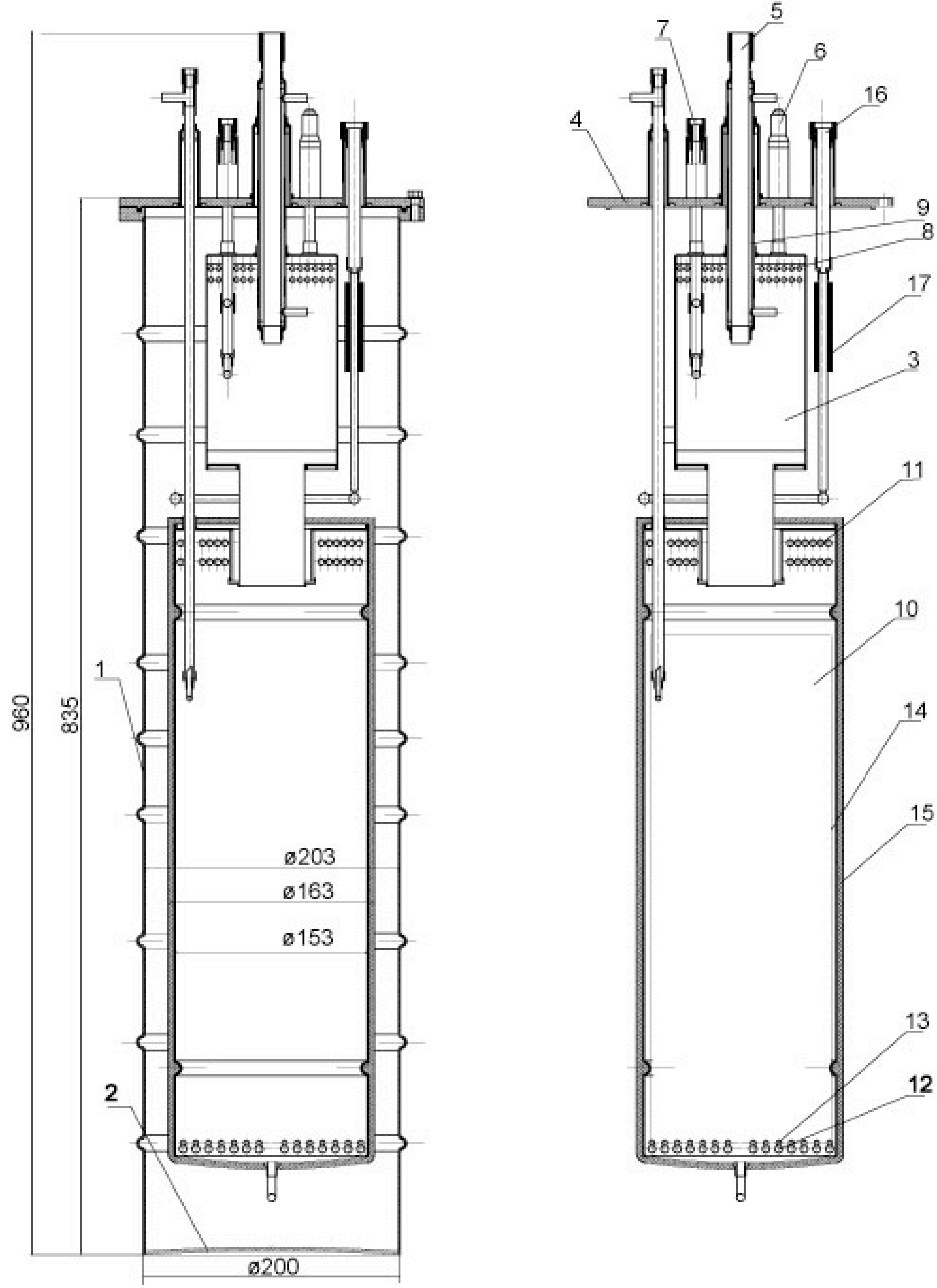


Fig.3. Xenon Recovery Cryostat

All cryostat connections located on the flange (4) are shown in the Fig.4.

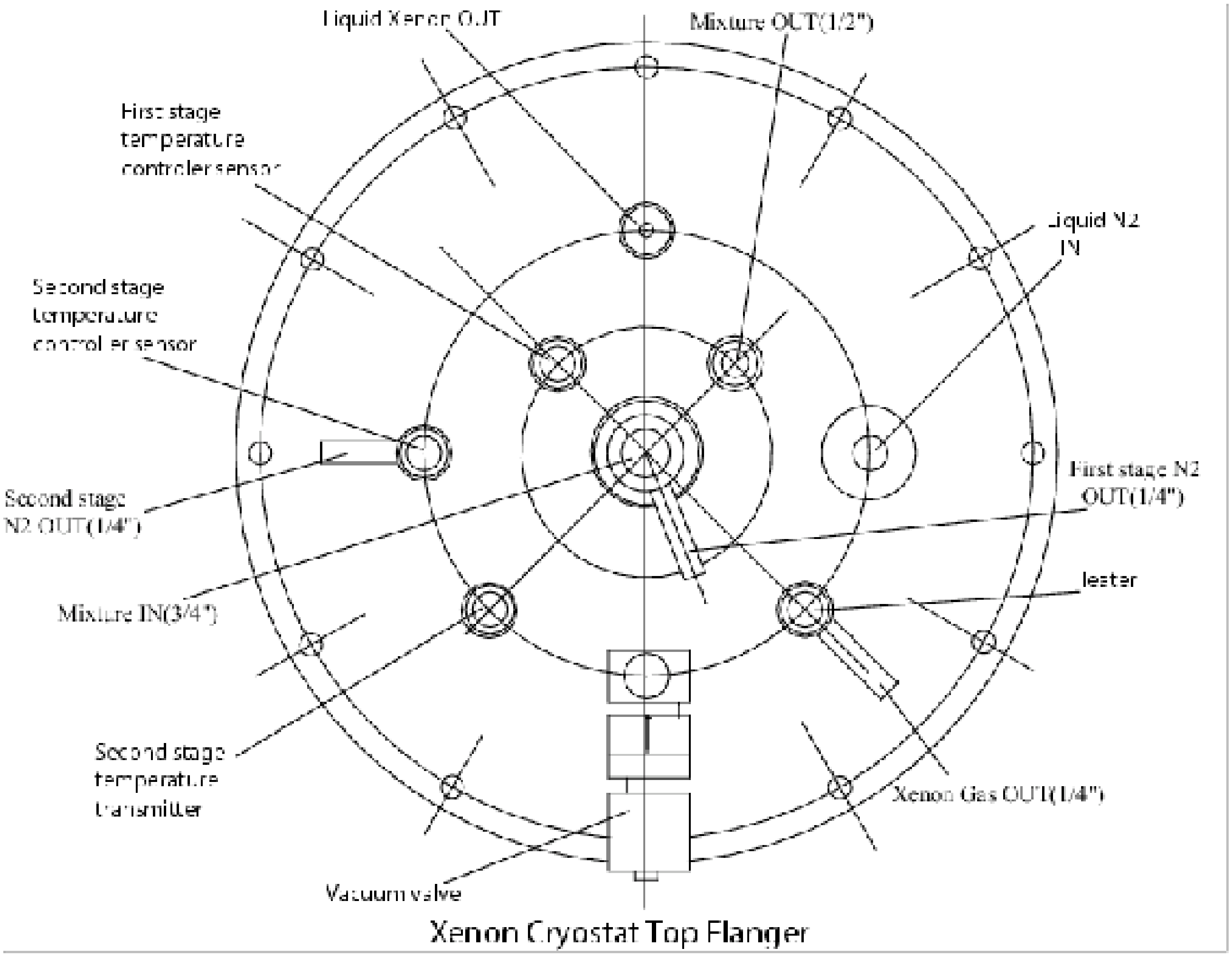


Fig.4. Xenon Recovery Cryostat Connections

Liquid Nitrogen is supplied through the connector 16 in Fig.3 to the first and second cryostat stages. The absorber, charcoal, (17) is used to support a stable vacuum level.

Nitrogen flow

Fig.5 shows a schematic of the N_2 flow through the cryostat heat exchangers.

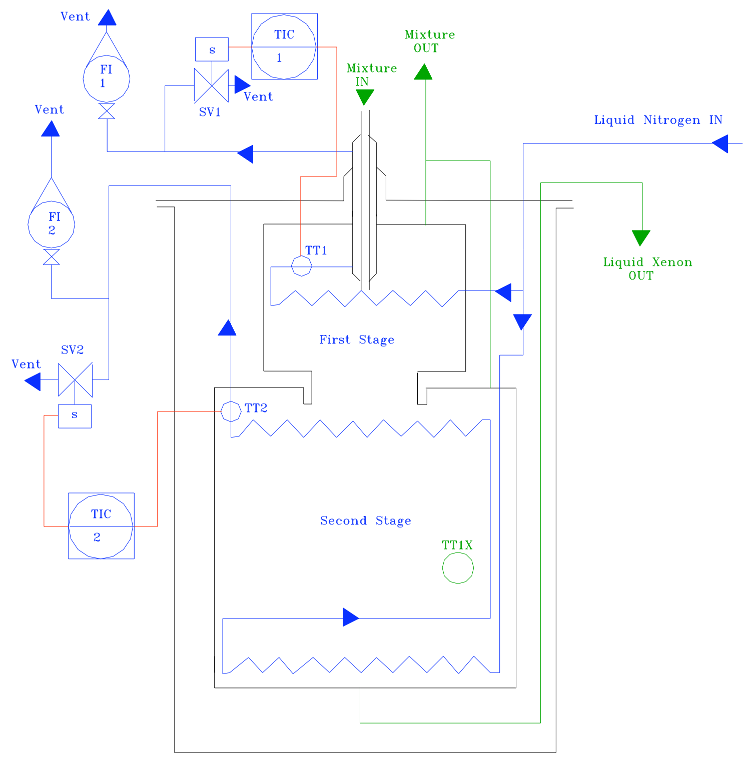


Fig.5. Nitrogen flows through the heat exchangers

Liquid N_2 from the storage vessels enters the two recovery stages with its flow controlled by a temperature-indicating controller (TIC) and monitored by thermometers TT1 and TT2. Part of the outgoing N_2 is used to pre-cool the incoming gas mixture and also to dilute the outgoing gas to non-flammable levels.

Xenon removal from the cryostat.

Xenon will be removed from the cryostats at 0.1PSIG (input and output closed).

The Xenon removal process from the cryostat to a commercial 6.9l stainless steel vessel will take 60-80 minutes under constant operator control. The operator will monitor the liquid N_2 level in the flask containing the 6.9l stainless steel vessel during the extraction process.

The second stage is heated to 164K to transform the solid Xenon into a liquid. A heater element reduces the heating time. Xenon is transferred into a 6.9 liters stainless steel vessel placed into liquid Nitrogen. After being disconnected from the cryogenic system the 6.9 liters vessel is heated up to room temperature and the Xenon gas is transferred into a 43.5 liters commercial storage cylinder for re-integration into the system. Appendix E shows the test result from of a pressure test of these commercial vessels.

Basic Xenon Cryostat parameters

Operating flow	0.5 liters/min
Purge flow	4 liters/min
First Stage Volume	1.3 liters
Second stage volume	8.6 liters
Operating pressure: Xenon collection Mode	0 atm (0 PSI)
Tested to, by L.Kotchenda	2 atm (30PSI, absolute)
Nitrogen consumption	~ 5 liters / 24hr
Cryostat weight	14.4kg (31.7lb).

System response to operating failures

Following is a list of possible failure modes and how the system is assigned to cope or recover from these failures:

- **Loss of vacuum**
  In this case the temperature values measured with TT1X and TT2X will exceed the set point of 130K and the TEC/TRD control system will inform the shift crew about this by an audible and optical alarm. Nothing will happen with the stages pressure because the cryostats outputs must be opened to the vent line for normal operation. If the output and input lines are accidentally closed the relief valves (PSV1, PSV2) will prevent overpressure.

- **LN_2 leak into vacuum space**
  To prevent overpressure inside the vacuum space the bolts on the cryostats flange, Fig.4, must be unscrewed for normal operation. The pressure load of about 700lb on the flange will be sufficient to keep high vacuum in the cryostats vacuum space. A startup checklist is required before operation is permitted.

- **Loss of power**
  In this case both cryostats inputs will be connected to the TRD vent line via SV5 (N/O) and SV6 (N/O) to collect Xenon. Nitrogen flow through FI1-FI4 will maintain the stage temperature close to set point controlled by the TICs at 160K for the first stage temperature and 110K for the second.

Pressure relief valve on the vacuum space.
Such valves will not be needed in this specific application, as the bolts on the flange will be removed for the normal operation mode, as mentioned above. A startup checklist is required before operation is permitted.

Relief valve on LN_2 lines.
These commercial lines can be operated at pressures up to 400PSIG, but being in line with valves

SV1-SV4, set to a maximum operating pressure of 40PSIG, the effective pressure in the lines cannot exceed this value.
The commercial LN2 dewars will be kept at 10PSIG pressure and have the relief valves. No liquid can be trapped inside the commercial transfer-lines as they do not have shut off valves.

Relief valves sizing

Appendix A contains a calculation of the pipe diameters and flow rates necessary for the relief valves PSV1 and PSV2. In case of bad vacuum the TICs will attempt to maintain the set point temperatures using more LN_2 compared to normal operation. If the second stage reaches a temperature of 130K the shift crew will be informed by the computer control.

Technical Specs of the Supply dewars

The N_2 supply dewars are commercial products by CRYOFAB (**www.cryofab.com**) who also manufacture the transfer-lines (Figs 2b and c).

Specs of the 200l N_2 supply dewars from the CRYOFAB web pages.

Net capacity (Liters)	25	50	100	200
Gross capacity (Liters)	28	55	110	220
Outer diameter (Inches/mm)	16/407	18/457	20/508	24/610
Height (Inches/mm)	28/711	33/838	41/1042	48/1220
Weight empty (lbs./Kg)	36/16.4	61/27.7	121/55	220/100
Weight full (lbs./Kg)				
LN2	81/36.8	150/68	299/136	577/262
LOX	99/45	187/85	373/170	724/329
LARG	111/51	211/96	421/191	820/373
Depth	22"	26"	35.5"	43"
M.A.W.P.	10 psig	10 psig	10 psig	10 psig
Static Loss/Day (CFN)	0.65/ltrs	0.70/ltrs	1.2/ltrs	1.2/ltrs
Neck Diameter (CFN)	0.75"o.d.	0.75"o.d.	1.0"o.d.	1.0"o.d.
Static Loss/Day (CFL)	0.87/ltrs	1.2/ltrs	1.3/ltrs	1.35/ltrs
Neck Diameter (CFL)	1.5"o.d.	1.5"o.d.	1.5"o.d.	1.5"o.d.

Specs of the open flask dewar from the CRYOFAB web pages

Model	CF8512"A" Inside Diameter (Inches)	"B" Outside Diameter (Inches)	"C" Inner Depth (Inches)	"D" Overall Height (Inches)	Gross Capacity (Liters)	Loss Rate (Liters/ Hr)	Liters/ Inch
CF9518	8.46	9.10	18.0	22.0	16.557	0.163	0.919

Appendix A:

<u>Estimation of Relief Valve for the Xenon Recovery Cryostat</u>
Performed by L. Kotchenda

Consider the worst case when 45%He+45%Xe+10%CH4 mixture is in the vacuum volume at 1 ata (absolute), all valves are closed, second cryostat stage contains 6l liquid Xenon at 1.07ata (165.15K), no N_2 coolant flow through the heat exchangers.

Assume, that the heat transfer to the volume with liquid Xenon takes place by means of the mixture thermal conductivity and the thermal conductivity coefficient (k) is estimated at 300K, room temperature.

$k=0.45 \times k_{He} + 0.45 \times k_{Xe} +0.1 \times k_{CH4}$,

with	k_{He}	=	0.153W/mK [1]
	k_{Xe}	=	0.034W/mK [1]
	k_{CH4}	=	0.005W/mK[1],
resulting in	k	=	0.085W/mK.

The thermal power is determined as

$Q = k \times (F/L) \times (T_1-T_2)$, where

F- second stage surface, m^2 ,

L- distance between the second stage wall and vacuum jacket the one, m,

T_1 – vacuum jacket wall temperature, K,

T_2 - second stage wall temperature, K.

The second stage has the following dimensions: outside diameter- 0.15m
height - 0.5m.

L = 0.025m.
T_1= 300K
T_2= 165.15K

Then $F = 0.785 \times (0.15^2) + 3.14 \times 0.15 \times 0.5 = 0.258m^2$

and

$$Q = 0.085 \times (0.252/0.025) \times (300-165.15) = 158.5W.$$

The mass amount of evaporated Xenon is

$m = Q/r$, where r - Xenon latent evaporation heat, J/g

$r = 95.5$J/g [1].

In this case

$m = 158.5/95.5 = 1.66$g/s .

Consider the case when the relief valve is connected directly to the first and second stages outputs, which are joined on the cryostat top. We have a rectangular connection to the relief valve.

The output dimensions are as follows:

First stage: inner diameter – 7.5mm
length - 115mm

Second stage: inner diameter – 7.5mm
length - 340mm

Consider the shortest first stage output.
Heat transfer to the first stage volume through the output SS pipe (8x0.25mm) is

$Q_1 = k \times F/L \times (T_1 + T_2)$, where

$F = 0.785 \times (0.008^2 - 0.0075^2) = 6.18\times10^{-6}\ m^2$ -pipe cross section,

K = 8.2W/mK in the temperature range of 165 –300K

Then $Q_1 = 8.2 \times 6.18\times10^{-6} \times (300 - 165.15) = 6.8\times10^{-3}$W

Suppose, that all amount of coming out Xenon gas is flowing through the first stage output pipe, then the gas temperature increasing can be estimated approximately as

$dT = Q_1/c_p \times m$, where c_p – Xenon thermal capacity at 165.15K

$c_P = 0.334$J/gK [1] and

$dT = 6.8\times10^{-3}/(0.334 \times 1.66) = 0.012$K

It means the outcoming Xenon gas will have a low temperature of

$T_{Xe} = 165.15 + 0.012 = 165.16$K

At this temperature and 1.07ata pressure Xenon specific volume is equal

$v = 0.1$l/g [1]

In this case the flow rate is

$V = v \times m = 0.1 \times 1.66 = 0.166$l/s = **10LPM**

The pressure drop along the first stage output line is estimated in the attached MathCAD file (Attachment 1).
In accord with the pressure drop calculations we have for the 7.5mm diameter and $Re_i = 2.071\text{x}10^4$

$$)p = \ )p_{2i} +)p_{4i} +)p_{mi} = 0.287 + 0.138 + 0.134 = \mathbf{0.559mBar}$$

The second MathCAD file (Attachment 2) contains the pressure drop calculations at the assumption when the relief valve is installed at a distance of 1m from the cryostat output and the Xenon gas has room temperature. The pipe has a 9mm inside diameter and the flow is 20LPM. In this case the pressure drop is

$$)p = ()p_{2i} +)p_{4i})_{115} + ()p_{2i} +)p_{4i} +)p_{mi})_1 =$$
$$0.287 + 0.138 + 2.478 + 0.985 + 0.175 = \mathbf{4.069mBar(0.06PSI)}$$

Conclusion :
Relief Valve has to have 1 psig Spring and flow rate more than 20LPM.
It may be Swagelok SS-8C –1 installed at 1m distance from the cryostat output using 9mm inside-diameter pipe.

References: 1. http://webbook.nist.gov/chemistry/fluid/

Attachment 1, MathCAD file

Pressure Drop Δp **mBar**

Performed by Kotchenda L

Laminar flow **Re** < 2000

Turbulent flow **Re** > 4000

Flow Rate V $\frac{m^3}{s}$

Density ρ $\frac{kg}{m^3}$

Diameter d **m**

Length l **m**

Dynemic viscousity μ **Pa·s**

Roughness ε **m**

Radius R **m**

Angle α **degree**

INPUT Parameters

Gas or Mixture Xenon

$V := 16.8 \cdot 10^{-5}$ $\rho := 9.8$ $\mu := 1.35 \cdot 10^{-5}$

$l := 0.115$ $d := 0.001$ $i := 1 .. 10$

$\varepsilon := 0.001 \cdot 10^{-3}$ $R := 0.01$ $\alpha := 90$

Colculations

1 $d_i := i \cdot d + 0.0005$

2 **Cross section**

$$s_i := 0.785 \cdot (d_i)^2$$

3 **Velocity**

$$v_i := \frac{V}{s_i}$$

4 **Reynolds**

$$Re_i := v_i \cdot \rho \cdot \frac{d_i}{\mu}$$

If $Re_i < 2000$ **then**

5 $\lambda 1_i := \frac{64}{Re_i}$

6 $\Delta p1_i := 0.5 \cdot \rho \cdot \lambda 1_i \cdot v_i \cdot v_i \cdot \frac{l}{d_i \cdot 133.322} \cdot 1.3332$

If **Re** 4.E3 ÷ 1.E5 **then**

7 $\square 2_i := \dfrac{0.3164}{(\mathbf{Re_i})^{0.25}}$

8 $\square \mathbf{p2_i} := 0.5 \cdot \square \cdot \square \mathbf{2}_i \cdot \mathbf{v_i} \cdot \mathbf{v_i} \cdot \dfrac{\mathbf{l}}{\mathbf{d_i} \cdot 133.322} \cdot 1.3332$

If Re 1.E5 $\square$ 1.E8 **then**

9 $\square \mathbf{3}_i := 0.032 + \dfrac{0.221}{(\mathbf{Re_i})^{0.237}}$

$$\square \mathbf{p3_i} := 0.5 \cdot \square \cdot \square \mathbf{3}_i \cdot \mathbf{v_i} \cdot \mathbf{v_i} \cdot \frac{\mathbf{l}}{\mathbf{d_i} \cdot 133.322} \cdot 1.3332$$

For rough pipes

10 $\square \mathbf{1_i} := \dfrac{\square}{\mathbf{d_i}}$

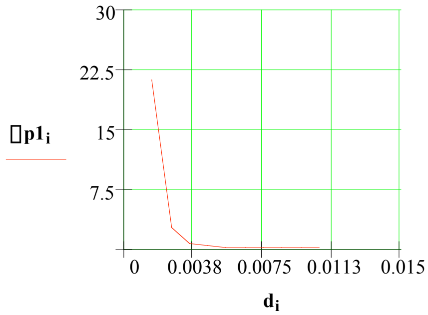
$$\square \mathbf{4}_i := \frac{1}{\left(1.74 + 2 \cdot \mathbf{log}\left(\frac{1}{2 \cdot \square \mathbf{1_i}}\right)\right)^2}$$

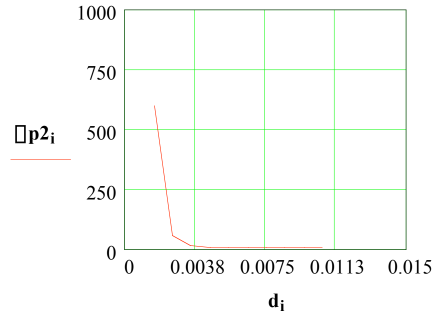
$$\square \mathbf{p4_i} := 0.5 \cdot \square \cdot \square \mathbf{4}_i \cdot \mathbf{v_i} \cdot \mathbf{v_i} \cdot \frac{\mathbf{l}}{\mathbf{d_i} \cdot 133.322} \cdot 1.3332$$

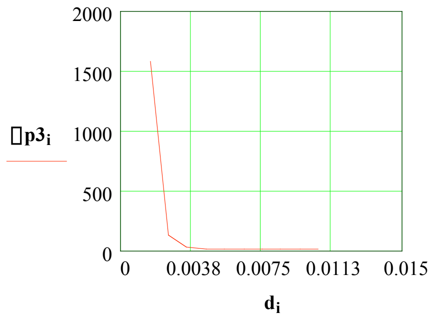
Local resistences
Bended pipes

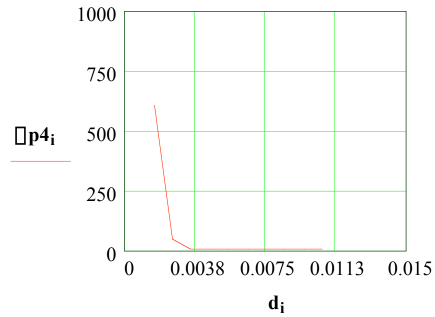
$$\square_{\mathbf{i}} := \left[0.131 + 0.16 \cdot \left(\frac{\mathbf{d_i}}{\mathbf{R}}\right)^{3.5}\right] \cdot \frac{\square}{90}$$

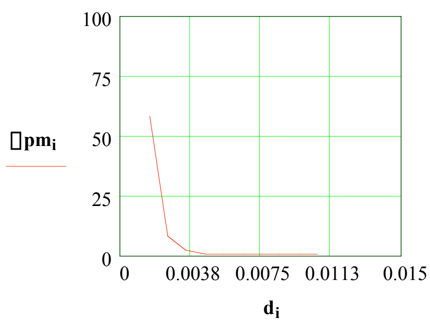
$$\square \mathbf{pm_i} := \square_{\mathbf{i}} \cdot \square \cdot \frac{(\mathbf{v_i})^2}{2 \cdot 133.322} \cdot 1.3332$$











d_i =	v_i =	Re_i =	$\Delta p1_i$ =	$\Delta p2_i$ =	$\Delta p3_i$ =	$\Delta p4_i$ =	Δpm_i =
$1.5\cdot10^{-3}$	95.117	$1.036\cdot10^{5}$	21.001	599.428	$1.574\cdot10^{3}$	605.805	58.166
$2.5\cdot10^{-3}$	34.242	$6.214\cdot10^{4}$	2.722	52.961	127.27	41.986	7.598
$3.5\cdot10^{-3}$	17.47	$4.439\cdot10^{4}$	0.709	10.711	24.323	7.262	2.02
$4.5\cdot10^{-3}$	10.569	$3.452\cdot10^{4}$	0.259	3.246	7.073	1.961	0.77
$5.5\cdot10^{-3}$	7.075	$2.825\cdot10^{4}$	0.116	1.252	2.64	0.69	0.37
$6.5\cdot10^{-3}$	5.065	$2.39\cdot10^{4}$	0.06	0.566	1.163	0.29	0.209
$7.5\cdot10^{-3}$	3.805	$2.071\cdot10^{4}$	0.034	0.287	0.576	0.138	0.134
$8.5\cdot10^{-3}$	2.962	$1.828\cdot10^{4}$	0.02	0.158	0.312	0.072	0.095
$9.5\cdot10^{-3}$	2.371	$1.635\cdot10^{4}$	0.013	0.093	0.181	0.04	0.073
0.011	1.941	$1.48\cdot10^{4}$	$8.747\cdot10^{-3}$	0.058	0.111	0.024	0.059

Kotchenda. L

Attachment 2, MathCAD file

Performed by Kotchenda L

Pressure Drop Δp **mBar**

Laminar flow $Re < 2000$

Turbulent flow $Re > 4000$

Flow Rate V $\frac{m^3}{s}$

Density ρ $\frac{kg}{m^3}$

Diameter d **m**

Length l **m**

Dynemic viscousity μ $Pa \cdot s$

Roughness Δ **m**

Radius R **m**

Angle α **degree**

INPUT Parameters

Gas or Mixture Xenon

$V := 32 \cdot 10^{-5}$ $\rho := 5.73$ $\mu := 2.31 \cdot 10^{-5}$

$l := 1$ $d := 0.001$ $i := 1 .. 10$

$\Delta := 0.001 \cdot 10^{-3}$ $R := 0.01$ $\alpha := 90$

Colculations

1 $d_i := i \cdot d + 0.000$

2 **Cross section**

$s_i := 0.785 \cdot (d_i)^2$

3 **Velocity**

$v_i := \frac{V}{s_i}$

4 **Reynolds**

$Re_i := v_i \cdot \rho \cdot \frac{d_i}{\mu}$

If $Re_i < 2000$ **then**

5 $\lambda 1_i := \frac{64}{Re_i}$

6 $\Delta p1_i := 0.5 \cdot \rho \cdot \lambda 1_i \cdot v_i \cdot v_i \cdot \frac{l}{d_i \cdot 133.322} \cdot 1.3332$

If Re 4.E3 ÷ 1.E5 **then**

7 $\lambda 2_i := \dfrac{0.3164}{(Re_i)^{0.25}}$

8 $\Delta p2_i := 0.5 \cdot \rho \cdot \lambda 2_i \cdot v_i \cdot v_i \cdot \dfrac{l}{d_i \cdot 133.322} \cdot 1.3332$

If Re 1.E5 – 1.E8 **then**

9 $\lambda 3_i := 0.032 + \dfrac{0.221}{(Re_i)^{0.237}}$

$\Delta p3_i := 0.5 \cdot \rho \cdot \lambda 3_i \cdot v_i \cdot v_i \cdot \dfrac{l}{d_i \cdot 133.322} \cdot 1.3332$

For rough pipes

10 $\varepsilon l_i := \dfrac{\varepsilon}{d_i}$

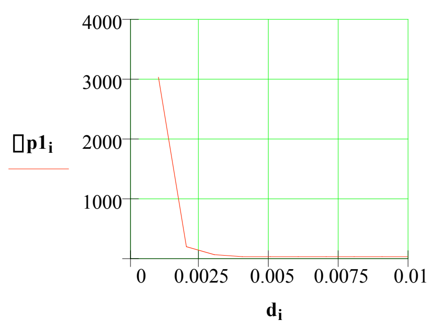
$$\lambda 4_i := \frac{1}{\left(1.74 + 2 \cdot \log\left(\frac{1}{2 \cdot \varepsilon l_i}\right)\right)^2}$$

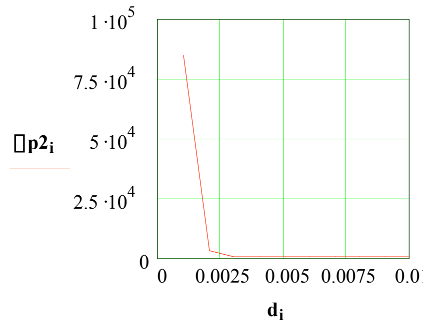
$$\Delta p4_i := 0.5 \cdot \rho \cdot \lambda 4_i \cdot v_i \cdot v_i \cdot \frac{l}{d_i \cdot 133.322} \cdot 1.3332$$

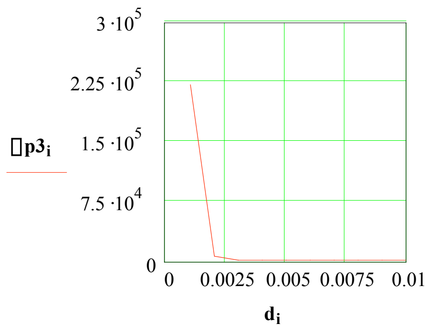
Local resistences
Bended pipes

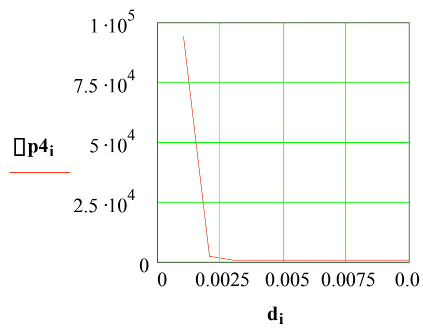
$$\zeta_i := \left(0.131 + 0.16 \cdot \left(\frac{d_i}{R}\right)^{3.5}\right) \cdot \frac{\alpha}{90}$$

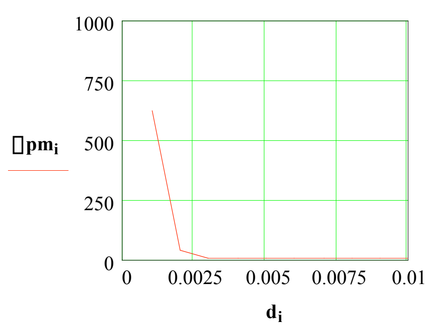
$$\Delta pm_i := \zeta_i \cdot \rho \cdot \frac{(v_i)^2}{2 \cdot 133.322} \cdot 1.3332$$











d_i =	v_i =	Re_i =	□p1$_i$ =	□p2$_i$ =	□p3$_i$ =	□p4$_i$ =	□pm$_i$ =
$1\cdot10^{-3}$	407.643	$1.011\cdot10^{5}$	$3.013\cdot10^{3}$	$8.447\cdot10^{4}$	$2.209\cdot10^{5}$	$9.344\cdot10^{4}$	623.904
$2\cdot10^{-3}$	101.911	$5.056\cdot10^{4}$	188.328	$3.139\cdot10^{3}$	$7.285\cdot10^{3}$	$2.483\cdot10^{3}$	39.149
$3\cdot10^{-3}$	45.294	$3.371\cdot10^{4}$	37.201	457.492	992.866	299.186	7.839
$4\cdot10^{-3}$	25.478	$2.528\cdot10^{4}$	11.771	116.661	241.739	66.809	2.557
$5\cdot10^{-3}$	16.306	$2.022\cdot10^{4}$	4.821	40.421	80.867	20.909	1.106
$6\cdot10^{-3}$	11.323	$1.685\cdot10^{4}$	2.325	17.002	33.069	8.1	0.58
$7\cdot10^{-3}$	8.319	$1.445\cdot10^{4}$	1.255	8.175	15.532	3.635	0.351
$8\cdot10^{-3}$	6.369	$1.264\cdot10^{4}$	0.736	4.335	8.073	1.816	0.237
$9\cdot10^{-3}$	5.033	$1.124\cdot10^{4}$	0.459	2.478	4.534	0.985	0.175
0.01	4.076	$1.011\cdot10^{4}$	0.301	1.502	2.706	0.57	0.139

Kotchenda. L

Appendix B:

<u>Xenon Recovery System Startup procedure</u>

to be executed by an expert only.

Task	Check if done
Connect vacuum pump	
Establish vacuum (10^{-3} Torr)	
Remove screws on top flanges	
Disconnect vacuum pump if vacuum stable (10^{-3}Torr)	
Turn On AC power to Xenon Cryostat Rack	
Turn On TIC1-TIC4	
Set TIC temperature: first stage: -113^{o}C (160K) second stage: -163^{o}C (110K)	
Set dewar pressure to 7 PSIG using cylinders PCV and MV1, MV2 (Fig2b)	
Set FI1 and FI3 flow to 1LPM and FI2 and FI4 to 2LPM	
Open Cryostats Outputs(MV2,MV4-open) and Inputs(MV1, MV3-open) for Purging TEC Mode with Mixture containing Xenon. Close MV Bypass 2(Fig.1, Fig.2)	
Unblock Alarm TT1X-TT2X on TEC/TRD PC below 130K For normal operation leave one cryostat open and close MV3 on the second one	
Open MV10-MV13 (Fig.2)	
Check scale, at 30lbs connect the second cryostat(MV3 open) and disconnect (MV1 close) the first one (Fig.2)	
Block Alarm TT1X on TEC/TRD PC	

Name: ____________________________________ Date: _____/______/_____

Appendix C:

Removal of Liquid Xenon from Cryostat

to be executed by an expert only.

Task	Check if done
1. Set TIC1-TIC2 temperature to -109^{o}C (164.2K).	MV-1 closed, MV-3 open. TT1X blocked
2. Turn heater 1 ON and let the temperatures stabilize.	
3. Close MV2, MV12 and MV13.	
4. Cool down 6.9L SS Cylinder with lqN2 in the flask.	MV6 –MV9 closed
5. Open 6.9L SS Cylinder Valve, slightly open MV5, let Xenon flow to SS Cylinder .	
6. Watch scale readings and lqN2 level in the flask.	
7. Close MV5 at every 10lbs interval on the scale.	
8. Heat up 6.9L SS Cylinder to reach 1400PSIG pressure.	
9. Replace Xenon from 6.9L SS Cylinder to 43.5L Cylinder.	
10. Repeat steps 4-9 twice to reach to ZERO scale reading.	
11. Turn OFF Heater 1 and set TIC1-TIC2 temperature to normal Operation Mode, first stage -113^{o}C (160K), the second -163^{o}C (110K).	
12.Open MV12-MV13 and MV2.	
13.Unblock Alarm TT1X below 130K.	

Name: ____________________________________ Date: _____/______/_____

Appendix D:

Removal of Xenon Gas from Cryostat

to be executed by an expert only.

Task	Check if done
1. Set TIC1-TIC2 temperature to -108^{o}C (165.2K)	MV1 closed, MV3 open. TT1X blocked
2. Turn heater 1 on and let the temperature stabilize	
3. Close MV2, MV12 and MV13 at –109^{o}C(164.2K)	
4. Cool down 6.9L SS Cylinder with lqN2 in the flask	MV6 –MV9 closed
5. Open 6.9L SS Cylinder Valve, MV9 and slightly open MV7, let Xenon flow to Cylinder	
6. Watch scale readings and lqN2 level in the flask	
7. Close MV7 and MV9 at every 10lbs interval on the scale.	
8. Heat up 6.9L SS Cylinder to reach 1400PSIG pressure.	
9. Replace Xenon from 6.9L SS Cylinder to 43.5L Cylinder.	
10. Repeat steps 4-9 twice to reach to ZERO scale reading.	
11. Turn OFF Heater 1 and set TIC1-TIC2 temperature to normal Operation Mode, first stage -113^{o}C (160K), the second -163^{o}C (110K).	
12. Open MV12-MV13 and MV2	
13. Unblock Alarm TT1X below 130K	

Name: ____________________________________ Date: _____/______/_____

Appendix E:

Results from the pressure test of the stainless steel flasks

An independent company tested the stainless steel flasks, used for extracting the liquid Xenon from the cryostat and converting it back into gas. Attached is a copy of the fax documenting the test.

KAPLAN INDUSTRIES INC.
COMPRESSED GAS CYLINDERS

ROUTE 73 & MORRIS AVENUE
MAPLE SHADE, NJ 08052
PHONE: (800)257-8299 FAX: (856)779-8242
E-MAIL: kaplan@kaplanindustries.com
WEBSITE: www.kaplanindustries.com

DATE: 11/25/02

OF PAGES: 2

TO: Carter Biggs

COMPANY: National Labs

PHONE: 631-344-7575

FAX: 631-344-4592

FROM: Jim Johnston

FREDLOV Inc. Ultra Test-10

Kaplan Industries
Rte 73 & Morris Ave.
Mapleshade, N.J. 08052

<u>High Pressure Cylinder Retest Report</u>

<u>Registration #: A622</u>

Disposition Codes
PA - Passed Hydro & Visual
FH - Failed Hydro

I hereby certify that the following tests were made under my supervision & in accordance with applicable regulations.

Operator Signature: ________ Date: 10/23/02 Supervisor Signature: ________ Date: 10/24

#	Cylinder Serial #	Size	Customer	Last Gas Serv	Mfgr.	Mfgr. Date	Specification/ Rating	Pressure Test	Pressure Act.	Test: Time:	Volumetric Expansion (cc) Total	Perm	% Perm	Elas	REE	+	*	Visual	Disp or Remark	Note
4	13853	6X28	WELCO	INER	WK	12-67	3AA2000	3165	3215	30	25.7	1.0	3.9	24.7	9999			PASS	PA	
5	26237	6X28	WELCO	INER	WK	12-67	3AA2000	3165	3265	30	28.6	2.8	9.8	25.7	9999			PASS	PA	